Experimenting with Incandescent Lamps

By Forrest M. Mims, III

The ancient incandescent lamp may seem to be rather low-tech for a magazine with the name *Modern Electronics*. Actually, though, some very significant advances have been made in the field of incandescent lamps, about which I shall have more to say later. I'll then present some experiments and circuits you can try that may cast a new light on the versatility of an antique electronic component we all take for granted. First, let's pause for a brief review of the history of the invention of the incandescent lamp.

The Invention of the Incandescent Lamp

Though Thomas Edison is generally credited with the invention of the incandescent lamp, other inventors also played a prominent role in this area. In 1802, England's Sir Humphry Davy demonstrated that an electric current passing through a thin strip of platinum would cause the metal to emit a visible glow. All modern incandescent lamps are derived from this fundamental discovery.

In 1841, Frederick de Moleyns received an English patent for an incandescent lamp that consisted of a two closely spaced platinum electrodes installed in an evacuated glass sphere. Powdered carbon between the electrodes became incandescent when an electrical current flowed through the two electrodes.

In 1850, Sir Joseph W. Swan, another Englishman, devised incandescent filaments from paper and cotton thread. He treated the thread with sulfuric acid to remove everything but the carbon. The carbonized thread was installed inside an evacuated glass envelope to produce what Swan called an electric glow lamp.

In the United States, Thomas Edison announced, in 1878, that he intended to invent a practical electric light suitable for use in homes. Based on his reputation as a highly successful inventor, a syndicate of investors advanced Edison $50,000 for the electric light project. The investors even formed the Edison Electric

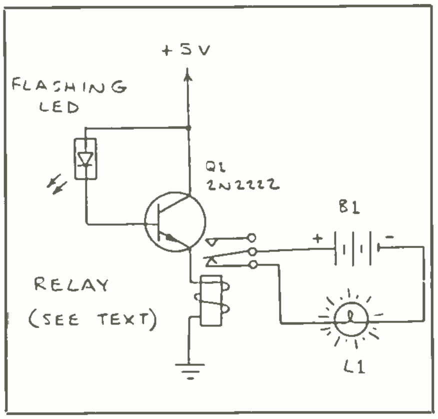

Fig. 1. A simple relay lamp flasher.

Light Company before the inventor had made his first lamp.

Edison at first attempted to find a filament material that could be heated to a higher temperature than the carbon used by his predecessors, thereby providing a brighter and more practical light source. Oxides of thorium and zirconium seemed good candidates, but they could not be formed into filaments. Finally, Edison resorted to the carbonized thread filament, and on October 21, 1879, he demonstrated a lamp that operated continuously for 40 hours. Two months later, he demonstrated a pilot light and power station at his Menlo Park, NJ laboratory. The system powered 30 lamps, any one of which could be disconnected without affecting the status of the others.

Incidentally, it's interesting to note that, from the outset, Edison proposed to connect electric lamps in parallel circuits so that the failure of one lamp would not affect the remainder. Some scientists predicted the parallel method would not be practical. Sir William H. Preece, for example, said as much in a paper he read before the Royal Society in London. Fortunately, Edison had only three months of formal education in his youth, so he could safely ignore the pronouncements of formally trained scientists. Of course, the parallel electric light circuit proved practical and it greatly enhanced Edison's fame as a gifted inventor. (As for the skeptical Sir William's scientific legacy, I had never heard of him prior to preparing this column.)

Blackbody Radiation

Everything above the temperature of absolute zero, which is presumably everything, emits electromagnetic radiation. This is commonly known as blackbody radiation. As the temperature of an object increases, the flux of the radiation it emits increases and, conversely, its wavelength decreases.

Blackbody temperature is specified according to the Kelvin scale in which 0 Kelvin (K) equals −273.16 degrees Celsius. (The term degrees is not supposed to be used with the Kelvin scale but often is.)

Only when the temperature of an object becomes very warm does the radiation it emits become visible. As evidence of this, consider that the temperature of an electric heating element that emits a cherry-red glow is in excess of around 1,000 K. The filament of a white-hot tungsten-halogen lamp may reach 3,400 K. If the filament could be heated to 6,000 K without melting, it would emit light as white as that emitted by the sun.

It's appropriate to ask why the light from an object at 1,200 K appears to be a monochromatic red while that from an object at 6,000 K is white. The answer is that blackbody radiation has a very broad spectrum and is not monochromatic. Indeed, the peak wavelength of a cherry-red heating element at 1,200 K is around 2.4 micrometers in the infrared. In other words, the red glow from the heating element is only a small portion of the radiation it emits. Most of the radiation from the heating element is invisible. The peak wavelength of sunlight is around 555 nanometers in the green. The fact this happens to match the visible response of the human eye is certainly no coincidence.

Tungsten Filament Lamps

The simplest tungsten lamp consists of either a straight or coiled tungsten filament installed in an evacuated glass envelope. The filament begins to emit a dimly visible red light at a temperature of around 1,000 K. In normal operation, the filament of an evacuated tungsten lamp is typically heated to a temperature of 1,800 to 2,200 K. The peak wavelength of an evacuated tungsten lamp with a filament temperature of 2,000 K is around 1.5 micrometers in the near infrared. Only around 5 percent of the optical radiation emitted by the filament is visible light; the remainder is invisible infrared.

If the filament is operated at a temperature higher than about 2,200 K, the rate of tungsten evaporation from it will become so high that the inside of the envelope will quickly become coated with an opaque film of tungsten atoms. Once I mistakenly applied far too much current to a miniature incandescent lamp. The filament exploded in a brilliant flash and coated the inside of the glass envelope with a shiny film of tungsten.

Tungsten lamps can be operated at a temperature higher than 2,200 K if the envelope is filled with an inert gas, such as argon or krypton, which reduces the evaporation of tungsten from the filament. The upper limit is 3,600 K, the melting point of tungsten. Since gases conduct heat, the envelope of a gas-filled lamp will become much hotter than that of an evacuated lamp.

Even better performance can be achieved by adding to the fill gas a trace of a halogen, such as bromine or iodine. This sets up a regenerative chemical reaction that greatly increases the permissible operating temperature of the filament while simultaneously restoring the tungsten atoms that are boiled away. Here's what happens:

In an ordinary lamp, tungsten atoms boiled away from the incandescent filament can condense on the comparatively cool inside wall of the glass envelope. In a halogen lamp, evaporated tungsten atoms combine with the halogen to form tungsten bromide or tungsten iodide. While this gas does move toward the inside walls of the envelope, it does not condense there when the envelope is heated to 200 to 250 degrees C by the filament, which may have a temperature of from 2,800 to 3,400 K.

As the gas circulates back toward the heated filament, it disassociates back into tungsten and halogen vapor when the temperature exceeds 2,500 K. This process occurs in close proximity to the filament, thereby causing tungsten atoms to be deposited onto the filament and its supporting wires. The cycle then repeats as additional tungsten is liberated and combines with halogen vapor.

The very high filament temperature made possible by the halogen cycle provides an exceptionally bright light source. Moreover, after 75 percent of its rated life, a tungsten-halogen lamp emits 90 percent of its initial light output.

The brilliant white light of a tungsten-halogen lamp is accompanied by several drawbacks. The envelope temperature of a tungsten-halogen lamp must exceed 200 to 250 degrees C and may reach 350 degrees C. This means ordinary glass envelopes are unsuitable. Instead, fused silica (quartz) is required. Special ceramic sockets are usually necessary, and there may be restrictions on the operating orientation of the lamp to prevent thermal damage to the lamp's seals.

Due to the high temperature required to fabricate fused silica envelopes, halogen lamps are more expensive than are conventional lamps. They must never be operated near combustible materials. They must never be touched while in operation. Any fingerprints or other contamination must be completely removed from the envelope before operation. Finally, the very high brightness of halogen lamps, coupled with the ultraviolet that they emit, makes them potentially hazardous to unprotected eyes.

The filament of an incandescent lamp requires a finite rise time to reach its operating temperature after a current is applied. Likewise, the filament requires a

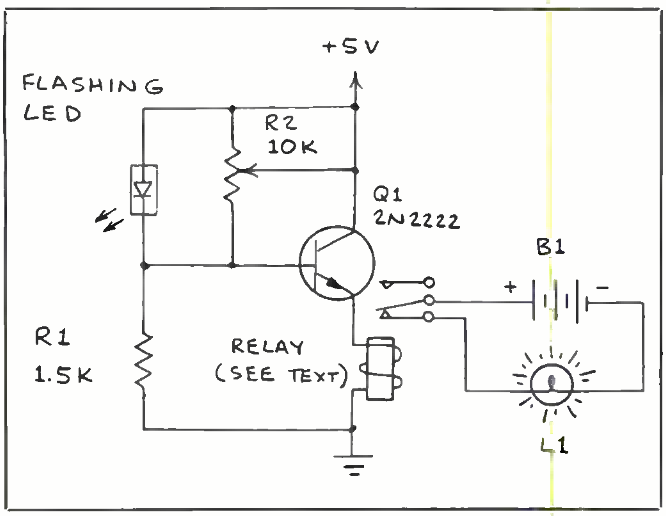

Fig. 2. An improved relay lamp driver.

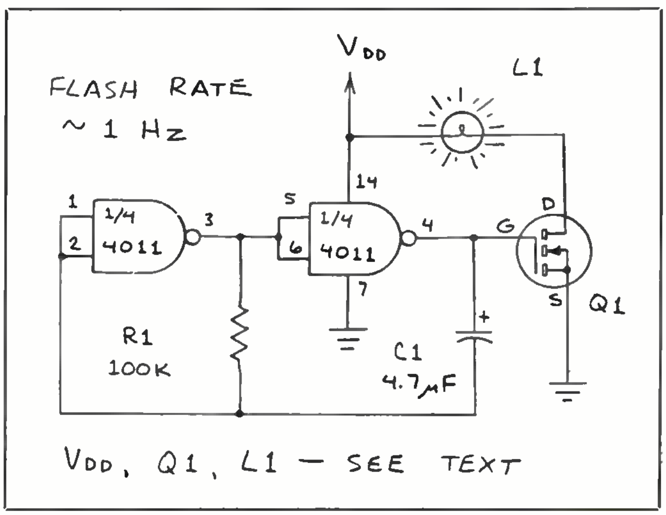

Fig. 3. A simple CMOS lamp flasher.

finite fall time to cool below the temperature where it emits visible light when the current is removed. These delays are sometimes known as thermal lag.

Thermal lag is directly related to the physical dimensions and mass of a lamp's filament. Because of the tiny size of its filament, the light from a flashlight appears to switch on and off instantaneously. Automobile headlights have very large filaments and require a noticeable time to achieve full brilliance when switched on and to be extinguished when switched off. The same applies to filament lamps used on tall antenna towers. The xenon strobe lamps used on some towers flash off and on almost instantaneously. The filament lamps used to mark most towers seem to switch off and on as if they were powered by an undulating sine wave.

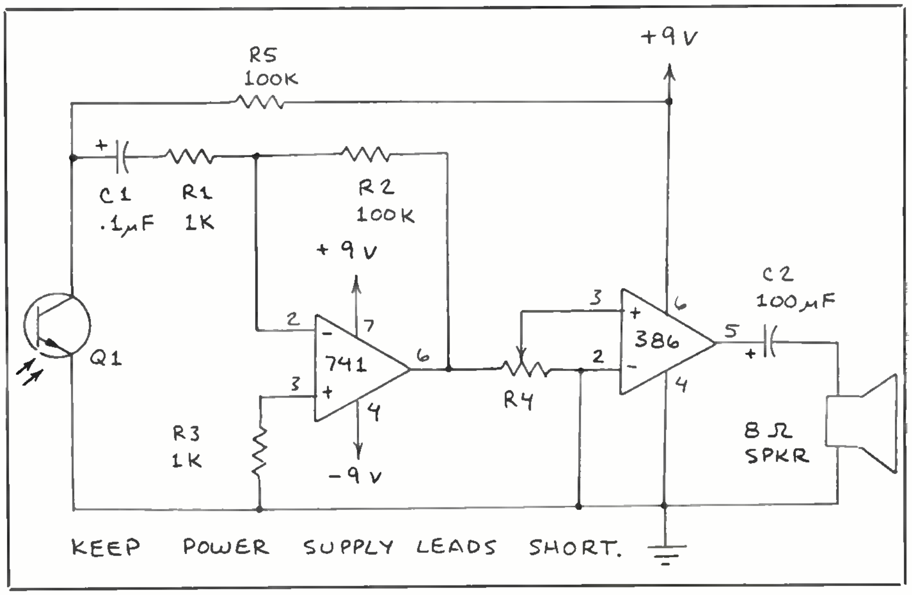

Fig. 4. A simple lightwave receiver circuit.

Relay Lamp Flashers

A relay is physically larger than a semiconductor switch, such as a silicon-controlled rectifier (SCR) or power MOSFET. Also, a relay requires a drive current that a semiconductor switch does not. Nevertheless, relays are exceptionally reliable and provide a very low on-resistance. Therefore, they are well suited for use in lamp flashing applications.

There are many ways to switch a lamp off and on by means of a relay. Circuits made from 555 timer chips are particularly popular since flash rate and duration is easily varied.

Figure 1 shows a super-simple relay lamp flasher you can assemble from a flasher LED and a single transistor. This flasher LED switches the transistor on each time it flashes, thereby pulling in the relay arm and switching on the lamp. I used an FRL-4403 flasher LED in the prototype of the Fig. 1 circuit. This LED flashes around three times per second. Other flasher LEDs should also work.

The relay should have a 6- to 9-volt, 500-ohm coil, such as Radio Shack's Cat. No. 275-004 relay does. Unfortunately, this relay is no longer stocked by Radio Shack; so you will have to search your spare-parts box or borrow one from a friend if you want to experiment with this particular relay. Other low-voltage (5-volt) relays with a high coil resistance may also work in the Fig. 1 circuit.

The flasher LED in Fig. 1 does not emit visible flashes when used as shown. Figure 2, a modified version of the circuit, permits the flasher LED to flash in step with the incandescent lamp. This verifies that the circuit is functioning properly in the event the incandescent lamp burns out.

In operation, *R2* must be adjusted until the lamp begins to flash. It may sometimes be necessary to readjust the setting of *R2* if the circuit stops flashing. While the flasher LED does emit a visible flash, it isn't as bright as when the flasher LED is used alone.

Power MOSFET Lamp Flasher

Figure 3 shows a simple incandescent lamp flasher circuit that uses a solid-state switch instead of a relay. The two cross-coupled gates form a multivibrator that oscillates at a frequency determined by *C1*. When the value of *C1* is 4.7 microfarads, the circuit oscillates at a rate of about 1 Hz. The output of the oscillator goes to the gate of VN67 or similar power MOSFET *Q1*, which is switched off and on by the changing state of the oscillator's output. The lamp is switched on when *Q1* is conducting.

Supply voltage for the Fig. 3 circuit should not exceed the lamp's rated voltage. Power dissipation of the lamp should not exceed *Q1*'s power rating. In some applications, when *L1* switches on, supply voltage might fall enough to alter the flash rate. If this is a problem, simply disconnect the lamp from the oscillator's power supply and provide it with a separate supply. The source lead of *Q1* should be connected to the ground side of both supplies.

For more versatility, replace the simple two-gate oscillator with a 555 or 7555 (CMOS 555) oscillator chip.

Modulating a Filament

In the spring of 1966 when I was a student at Texas A&M, I was experimenting with a lightwave communication system along a dark country road. The receiver's detector was a solar cell installed inside the reflector of a 6-volt lantern light. The receiver emitted a buzz when it was pointed at a distant neon sign. More surprising were the ringing sounds caused by the headlights of some passing cars.

Later, I tried pointing a flashlight at

the receiver, which produced nothing but changes in noise level. Tapping the flashlight with a pencil caused the receiver to emit the same ringing sound produced by the car headlights. The ringing is caused when the filament vibrates in and out of the reflector's focal point.

You can make a lightwave receiver to observe this phenomenon by connecting a silicon solar cell to the input of a battery-powered amplifier. Alternatively, you can assemble the basic lightwave receiver circuit shown in Fig. 4. In this circuit, *Q1* is any npn phototransistor. Do not place your ears close to the speaker since it is capable of emitting very loud sound levels.

The rise time of miniature, low-voltage lamps may range from 10 to 200 milliseconds. This means a small lamp can be modulated at audio frequencies. Indeed, during World War II, some amateur radio operators experimented with optical communicators based on voice-modulated incandescent lamps.

G. Wataghin and R. Deaglio of Torino, Italy first published a brief note on this method in a 1933 issue of the *Proceedings of the Institute of Radio Engineers* (Vol. 21, No. 10, pp. 1495-6). Hollis French presented complete construction details for a battery-powered filament lamp transmitter and receiver in the April 1944 issue of *QST* (pp. 22-25 and 86-88). French's system operated in either blinker or voice mode. The former yielded a range of up to 12 miles, the latter up to 0.5 mile.

Incidentally, French didn't feel that a filament lamp could react rapidly enough to a fluctuating signal to produce a modulated light beam. He attributed the modulation to physical vibration of the lamp filament: "An ordinary flashlight pointed at the photo-tube and tapped with a pencil or other solid object will give a bell-like tone at the receiving end, proving that mechanical vibration will produce sound." French's conclusion was wrong, but he was decades ahead of me in discovering that a vibrating lamp filament produces a modulated light beam.

In the "Experimenter's Section" of the October 1944 issue of *QST* (p. 38), Roger Houglum observed that, "In practically all the light-beam transmitters described in *QST*, the audio-frequency current from a low-impedance winding on an output transformer is used to vary the intensity of the light from a flashlight bulb . . . . Tests with several of these transmitters revealed that the audio quality at the receiver end was passable on voice but downright poor when music was used."

Houglum then demonstrated how a small battery and low-resistance rheostat in series with the lamp and transformer winding would provide a pre-bias to warm the lamp filament to around half its

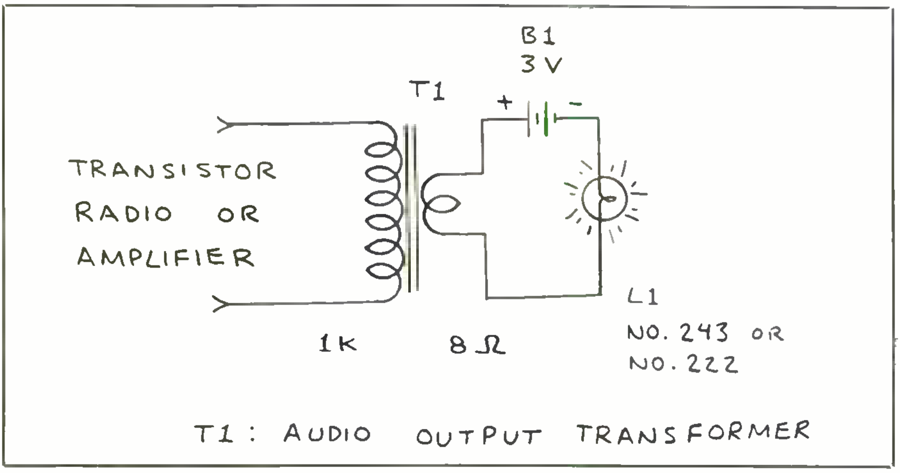

Fig. 5. An ultra-simple incandescent lamp audio transmitter circuit.

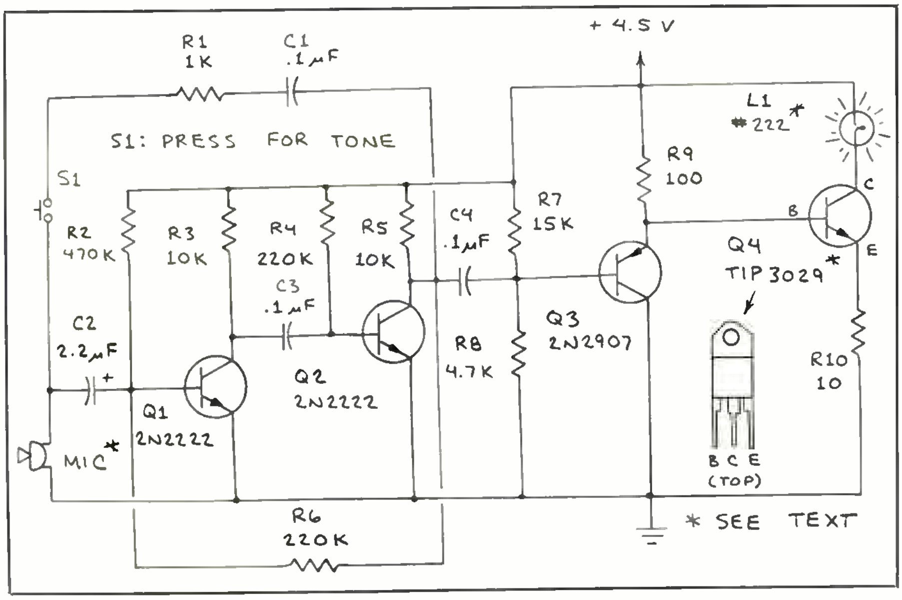

Fig. 6. An incandescent lamp modulator/driver circuit.

operational brilliance. This reduced the lamp's rise time and greatly improved its ability to be modulated by audio frequencies. The rheostat permitted the current to the lamp to be adjusted for optimum operation without zapping the lamp.

Lamp Modulators

Figure 5 shows the circuitry for an ultra-simple transformer lamp modulator based on circuits published nearly 50 years ago. You can assemble this circuit in just minutes. The simple receiver in Fig. 4 will receive the signal from this circuit. For initial tests, you can use a radio as an audio source or replace the radio with a small amplifier to transmit your voice.

While the low-impedance output from most transistor radios and amplifiers can be coupled into the 1,000-ohm (1k) winding of the audio transformer in the Fig. 5 circuit, much better results can be obtained if you connect a second transformer to the first. Connect together the 1,000-ohm winding of the two transformers. Then connect the 8-ohm winding of the new transformer to the output of the radio or amplifier.

You can control the brightness of the lamp by inserting a low-resistance rheostat in series with the lamp and *B1*. It's much simpler, however, to achieve the same effect by altering the volume of the amplifier or radio. In either case, it's important to keep peak current through the filament well below the point at which the filament melts.

Speaking of melted lamp filaments, chances are you will blow some lamps while experimenting with them in modulation circuits. Therefore, it's always a good idea to install lamps in sockets rather than soldering their leads into the circuit. Be sure to keep this in mind when building the following circuits as well.

In Fig. 6 is shown the circuitry of a transistorized filament lamp modulator/driver that modulates a small No. 243 or 222 lamp. As in Fig. 5, audio output transformer *T1* connects to a small radio or amplifier. The critical components are *L1* and *Q1*. If current through the collector-emitter junction of *Q2* is too high, *L1* may burn out or its life be excessively shortened. Momentary surges may not harm *Q2*, but the average current through the transistor and *L1* should not exceed 200 to 230 milliamperes.

You can measure the current through *L1* by breaking the circuit at point "X" in Fig. 6 and inserting an ammeter. Current can be reduced by lowering the level of the signal applied to *T1* or by inserting a current-limiting resistor at R_X.

If *Q2* becomes warm, install a heat sink on its case. For higher current operation, use a power MOSFET for *Q2*.

Self-Contained Lamp Transmitter

Figure 7 is the schematic diagram of a complete lightwave voice and tone lightwave transmitter that uses a miniature No. 222 lamp as a light source. Transistors *Q1* and *Q2* amplify the signal from the microphone and apply it to the modulator/driver circuit formed by transistors *Q3* and *Q4*. Resistor *R6* provides negative feedback to reduce the gain of the preamplifier formed by transistors *Q1* and *Q2*.

When *S1* is closed, the input preamplifier oscillates and causes the lamp to be modulated by an audio-frequency tone.

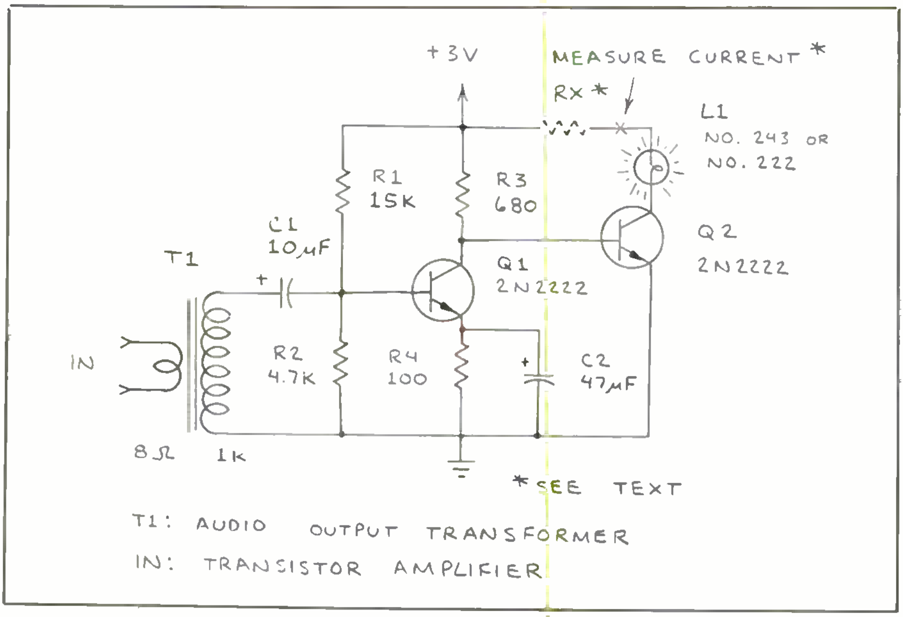

Fig. 7. A transistorized incandescent lamp voice and tone transmitter.

Frequency can be changed by altering the values of *R1*, *C1* or both.

The circuit should be powered by three 1.5-volt cells connected in series. Before connecting the cells to the circuit, however, connect the microphone and carefully check all wiring to make sure no errors have been made. When power is applied, the lamp should glow at around half its normal brilliance. If it glows a dim yellow in color, increase pre-bias current by connecting a second 10-ohm resistor across *R10*.

When you speak into the microphone, the lamp filament should flicker. Pressing *S1* may cause the lamp's brightness to change, but the lamp will not flicker.

Most dynamic microphones should work well with this circuit, but high-impedance types will not work. Though I used a TIP3029 for *Q4*, other npn power transistors should also work.

Going Further

Try placing a magnifying lens between a small incandescent lamp and a white wall. As you move the lens back and forth, an image of the lamp's filament will be projected onto the wall when the filament is at the focal point of the lens. This simple demonstration shows that a small fraction of the light emitted by a filament can be collected and collimated into a narrow beam.

You can make your own lens collimator or use binoculars or a small telescope. My son, Eric, and I have placed a small lamp at a telescope eyepiece and projected an image of the filament on a building more than a hundred meters distant. We then sent voice and music signals over the collimated beam to a receiver.

Since only a tiny fraction of an incandescent lamp can be collected by a lens, a reflector provides a more-efficient means for collimating light from a lamp. A laser, of course, provides a much better source of collimated light. But flashlight lamps and simple lenses are very inexpensive and with them, flashing signals, music and voice can be sent a fair distance on a dark night.

You may wish to do as I've done and assemble filament lamp transmitters and receivers inside plastic 6-volt lantern light housings. These large flashlights are equipped with reflectors and plenty of space for circuits and batteries. **ME**